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SCENARIOS WHICH MAY LEAD TO THE RISE OF AN ASTEROID-BASED TECHNICAL CIVILISATION

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Abstract—In a previous paper, the author described a hypothetical development path of technical civilisations which has the following stages: planet dwellers, asteroid dwellers, interstellar travellers, interstellar space dwellers. In this paper, several scenarios are described which may cause the rise of an asteroid-based technical civilisation. Before such a transition may take place, certain space technologies must be developed fully (now these exist only in very preliminary forms): closed-cycle biological life support systems, space manufacturing systems, electrical propulsion systems. After mastering these technologies, certain events may provide the necessary financial means and social impetus for the foundation of the first asteroid-based colonies. In the first scenario, a rich minority group becomes persecuted and they decide to leave the Earth. In the second scenario, a "cold war"-like situation exists and the leaders of the superpowers order the creation of asteroid-based colonies to show off their empires' technological (and financial) grandiosity. In the third scenario, the basic situation is similar to the second one, but in this case the asteroids are not just occupied by the colonists. With several decades of hard work, an asteroid can be turned into a kinetic energy weapon which can provide the same (or greater) threat as the nuclear arsenal of a present superpower. In the fourth scenario, some military asteroids are moved to Earth-centred orbits and utilised as "solar power satellites" (SPS). This would be a quite economical solution because a "military asteroid" already contains most of the important components of an SPS (large solar collector arrays, power distribution devices, orbit modifying rocket engine), one should add only a large microwave transmitter. © 2002 Elsevier Science Ltd. All rights reserved

1. INTRODUCTION

Traditionally, the question "Where are they?" (the extraterrestrials) is attributed to Fermi (see [1, p. 299]), but the first persons who, in detail, discussed this question in papers published in refereed journals were Hart (see [2]) and Viewing (see [3]). Their answer is that most probably they do not exist if we assume that interstellar spaceships can be developed in a reasonable time. It is generally agreed that such a development is technically possible in a not too long time (maximum several centuries if one starts from our present level of technology, see [4]). The pioneers of the traditional (radio) SETI generally consider interstellar travel as impossible, if not because of technical then because of financial reasons (see [5]). Sometimes it is also assumed by them that the longevity of the technical civilisations on their home planets (the last factor of the Drake equation) is rather short, less than a thousand years (see [6, p. 62]). A better alternative than this assumption is also possible: technical civilisations may gradually move into space and loose interest in planets.

If we look into the details of the Fermi paradox, then we can see that the hidden assumption behind it is the "Galactic Empire". It is not a scientific concept at all (it was invented by the early 20th century sci-fi writers and it is a favourite theme of the science fiction since then) but its extreme popularity seems to affect many scientists too. An early classification of the technical civilisations which was created by Kardashev (Type I,II,III civilisations utilising the resources of a planet, a stellar system, a galaxy, see [7]) is based on the same idea. In order to avoid the obvious contradiction with the

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experience, Kardashev invented the "Urbanisation Hypothesis" (see [8]). According to this hypothesis, all the advanced civilisations of a galaxy are moving into a "galactic city centre" (a disk-shaped area with several parsecs diameter). Unfortunately, there is no obvious mechanism which would force all the advanced civilisations to do so, and astronomical observations do not confirm (to date) the presence of such strong and (relatively) compact infrared sources near the galactic centre.

The concept of the "Galactic Empire" is a creation of analogic thinking, i.e. it is assumed that astronauts will fly between the habitable planets like 16th century colonisers sailed between the continents. Another version of this analogy compares the interstellar travellers to the Polynesians who colonised the islands of the Pacific (see [9]). Unfortunately, calculations based on this analogy with reasonable assumptions about interstellar travel times and distances, time necessary for establishing a colony etc. yield that the whole Galaxy could be colonised in several millions of years (see [10]), which contradicts with the obvious lack of interstellar colonisers in the solar system. But the ideas about the "not too difficult" interstellar travel can be the creations of "technological hubris" (see [11]), at least the enormous costs described in [5] cannot be ignored. It seems probable that technology alone cannot solve all the problems of interstellar travel without other helping factors. One such helping factor could be the biological evolution, which can provide quite effective and economic solutions. In this case, the proper analogy of space colonisation is not the colonisation of America (or the islands of the Pacific) but a much more ancient process: life's migration from water to land. Using this analogy, the paradox simply disappears: fishes never meet lizards or rats. (In the Earth's biosphere there are large groups of animals which live in a mixed water/land environment, but every analogy has its limits. Man's adaptation to the space environment, especially to weightlessness, probably will create a very effective and final barrier.)

Using this analogy, the author has invented a hypothetical development path which describes the evolution of technical civilisations originating in Earth-like planets (see [12]). The main steps of such an evolution are the following:

- Level 1 ("planet dwellers"): they live on the surface of a planet, biologically adapted to its surface conditions (strong gravity, high air pressure, low level of ionising radiation, natural food resources), utilise naturally conserved stellar energy (coal, oil, uranium) and raw materials mined from the planet's crust.
- Level 2 ("asteroid dwellers"): they live in small, non-rotating habitats built under the surface of asteroids, biologically adapted to the conditions of such habitats (near-zero gravity, low air pressure, food from a closed-cycle biological life support system, elevated level of radiation while working on the surface of the asteroid), utilise direct sunshine (solar cells, solar furnaces), mine raw materials from the asteroids.
- Level 3 ("interstellar travellers"): they live in limited-range interstellar spaceships, biologically adapted to the conditions of those ships (like level 2, but smaller closed-cycle life support system and permanently elevated level of radiation—a massive shield is impractical on a spaceship), utilise the same resources as the "asteroid dwellers" when they stop at a star, utilise stocked materials and energy (He3+D, antimatter?) during travels.
- Level 4 ("space dwellers"): they live in unlimited-range interstellar spaceships, biologically adapted to the conditions of those ships (like level 3, but probably an even smaller life-support system), utilise the interstellar medium (hydrogen + dust) for obtaining raw materials, obtain energy from the fusion of hydrogen or from exotic resources (vacuum zero-point energy?).

This "Evolution Hypothesis" could be proved (or disproved) by the detailed examination of certain near-Earth asteroids (see [12]). A part of this evolution path (utilisation of the various energy resources, although not mentioning the biological evolution) was published earlier by Tang and Chang (see [13]), but the author devised the above hypothesis independently. One may argue against this hypothesis that technological development is much faster than biological evolution, but it is true only under specific conditions. In a stable environment biological evolution is slow, but in case of catastrophes when the environment is changing quickly and radically, large populations are wiped out, leaving only small, isolated groups of plants and animals then new species (or at least subspecies) may appear within several generations (see [14]). Another example is the selection and breeding of plants and animals in a man-made environment which is known to yield new subspecies quickly. If there will be space colonists who will be subjected to the environmental conditions of relatively cheap space habitats for a long time, then

significant biological changes can be expected. O'Neill suggested the creation of very large and complex habitats ("space colonies", see [15]) in order to provide Earth-like conditions, but the creation of such million-ton structures in space will be a financial impossibility for a very long time even for the richest nations. The "high speed of technological development" is also questionable, there is really impressive progress in certain areas now (e.g. in circuit miniaturisation) but there are other key areas which show little or no progress for a long time (Earth-to-orbit transfer systems, controlled fusion, etc.). Those technologies which can be used in space habitats only (e.g. closed-cycle life support systems) are in especially bad position because of the very limited funding available for such developments.

The "Evolution Hypothesis" also has some advantages from the viewpoint of the Copernican Principle (i.e. if we choose an "arbitrary intelligent observer" then he or she should be an "average observer", not exceptional in any way). According to this hypothesis, Man is not an exceptional apex of the evolution but an intermediate step (like all the lower-level life forms) leading to higher level creatures. Life is not some strange feature of the Earth-like planets but gradually appears in the whole Universe. As Ball suspected in [16]: "More likely an Earth-like planet is to (highly developed) ETI what an empty eggshell is to a bird".

2. TECHNOLOGICAL PREREQUISITES

Right now we are not able to establish a colony on an asteroid, because some important space technologies necessary for this exist only in quite preliminary forms. Very substantial developments needed in the following fields:

- closed-cycle biological life support systems (CBLSS),
- space manufacturing systems,
- electrical propulsion systems.

Subsystems of CBLSS have been built and tested in several universities and space centres. Acceptable solutions exists for the most important subsystem functions: air revitalisation, water revitalisation, crop growth, food production, waste management (see [17,18]). But the models already built use rather ordinary laboratory equipment which is not intended for space usage (i.e. not designed to be small and light, work in weightlessness etc.). Long-term testing of a complete CBLSS with human inhabitants also has not been done yet. The famous Biosphere-II project is useless for this purpose because the Biosphere-II was created as a model of the Earth's biosphere, it contains many plants, animals and large masses of land and water. It is bulky, heavy and excessively complex, cannot be regarded as a model of a CBLSS intended for space usage.

There are two CBLSS functions which were not tested yet, but are necessary for very long term missions (i.e. colonisation):

- production of a detergent ("soap") and a disinfectant (e.g. alcohol),
- production of cellulose fibres.

The detergent and the disinfectant are necessary for cleaning purposes. Cellulose is produced in large quantities by the plants, but in the present CBLSS models it is considered as a waste product and simply burned. In a CBLSS intended for long-term use, a part of the produced cellulose must be converted into cellulose fibres. These fibres are necessary for making paper and threads. The paper is not needed for writing, but for cleaning and food packing. The threads are necessary for repairing clothes or even making new ones.

It must be mentioned here that most of the recent CBLSS experiments were done with higher level plants. These can be used easily to produce foodstuffs acceptable for human consumption, but these also have some disadvantages if one compares them with lower level plants (e.g. algae): they need soil and gravity, they don't grow very quickly and a significant part of their mass is unusable (roots, stalks, leaves). It is possible that a CBLSS which is effective enough for space utilisation (low mass, simple structures, etc.) can be built only with single-cell plants. But in this case, we still need significant developments for the food production parts of the CBLSS.

The space manufacturing system must produce everything which is necessary for the repairing and extension of the colony (airtight containers, furniture, motors, pumps, tools etc.). The operation of the space manufacturing system can be divided into the following major stages:

- conversion of the raw minerals ("stones") into raw materials (metals, silicon, silica etc.),
- producing the materials necessary for the manufacturing processes (alloys, glasses etc.),
- manufacturing the various end-products.

There are some solutions for the first step which were tested in laboratories (see e.g. [19]), the results are promising but far from being acceptable

(material efficiency and the quality of the products must be improved). In these tests, ordinary laboratory equipment was used, a real "space smelter" has not been built yet. For the second step, there are some furnaces which were tested in zero-g environment, but these furnaces were intended to produce special alloys and crystals in small quantities. To produce common alloys (e.g. duralumin) in large quantities, efficiently (i.e. utilising sunshine directly), in zero-g environment, one must build a different furnace, such a device has not been built yet.

The manufacturing of the end-products is a very problematic issue. It is frequently assumed that manufacturing processes used on the Earth can be used in space only with minor modifications but this is not true. Because of the space environment (vacuum, weightlessness, etc.) many technical details (lubrication, cooling, etc.) must be re-designed, but this is only the smaller part of the problem. The bigger part is the whole method. On the Earth, we use highly specialised machines (built from very many different parts) with which an end-product can be produced efficiently in large quantities, but in many steps. For producing many different end-products we use many different machines. In a space manufacturing system this is not acceptable, there should be only several general-purpose machines. These machines must be versatile, not too complex (not containing many special parts, easy to use and repair), not too heavy and bulky but robust, and efficient in mass production, too. The design of such machines (and the appropriate manufacturing procedures) is a very difficult task, we are very far from an acceptable solution (see [20]). Probably, this is the greatest technical problem which must be solved before one may establish a permanent base on an asteroid.

Powerful electrical propulsion systems must be developed for the asteroid-based colonies because the asteroid dwellers sometimes must travel from one asteroid to another (it is probable that they cannot find all the necessary minerals on a single asteroid) or to the Earth and back (in the beginning—this may mean decades—they will not be able to produce everything locally, they will have to import high precision parts, ultra-pure materials etc. from the Earth). Conventional chemical rockets are not suitable for them because ordinary (stony) asteroids do not contain volatiles in large quantities (at least not in easily accessible forms) and the extinct comet nuclei have grave disadvantages (orbits with high eccentricity, lack of metal-bearing minerals, etc.). For the initial delivery of the "bootstrap" modules to the first asteroid, one may also consider the use of electric rockets, the utilisation of such rockets may make the travel times longer (although it depends on many factors, e.g. if a fly-by acceleration trajectory is not available for the chemical rocket or the electric rocket is very powerful, then the latter one might be quicker), but the weight which must be raised to Earth orbit will be smaller.

The most promising electrical propulsion systems are the mass drivers (see [21]) and the ion engines (see [22]). These are not very heavy, do not need large reaction masses and can use many different materials as "ejected mass". Mass drivers exists only as laboratory test devices. Ion engines were flight tested on several spacecrafts (NASA's SERT-II and DS1, the Japanese ETS-VI etc.), too. All the existing devices are able to produce only a small thrust, i.e. they are usually used as "orbit trim" or "station keeping" engines. The only exception to date is the DS1, on this spacecraft the ion thruster was used for major trajectory modifications, too (the achieved delta V was approximately 2.6 km/s after 365 days of summarised operation time). A mass driver ejects the reaction material in pulses, the force exerted during a pulse is rather great, but the pulses in the existing devices cannot be repeated quickly, i.e. the average thrust is small. It would be necessary to create and test (in space) much more powerful devices which can be used as "orbit injection" engines, too. In connection with it, one must build more powerful and/or more efficient solar arrays (or other types of solar power converters) in order to provide the necessary electrical power (several MWs at least).

One may note here that the chemical rockets existing now are powerful enough for starting an asteroid colonisation venture. The largest chemical rockets can raise payloads of more than 100 tons to low-Earth orbit. A 80–100 ton module can be delivered to a near-Earth asteroid with a 30 ton electrical propulsion engine (including the solar power converters and the reaction mass), and with 10–15 such modules an asteroid colony perhaps might start to operate. Therefore, the number of the necessary launches is not much bigger than in the Apollo project, although the development cost before the launches would be orders of magnitude greater if all the developments mentioned above must be done in the same project. But it is not impossible that within the "general progress of technology" some of the above mentioned technologies will be developed "silently", in this case the development cost of an "asteroid colonisation project" may become acceptable, too.

3. THE "ESCAPIST" SCENARIO

Persecuted minority groups are quite common in history. Even rich minorities might become persecuted. It is not impossible that such a minority group, after being expelled from some or many countries, decides to found a new homeland. In case of an overpopulated and polluted Earth, a location outside the Earth could be a reasonable choice (the cost of establishing a colony is immense, and they cannot take the old or weak members there, but they will have a large space to grow, and there will not be enemy neighbours, i.e., there will be no defence costs). In case of a well organised and zealous group (with many skilled members), the members may perform significant tasks in the colonisation project without payment, in this case even the cost might be not so immense. One may think that the Moon would be a better place for such an escapist colony than an asteroid, but it is not necessarily true. The Moon's gravity is rather strong, one must use chemical rockets there. According to the common interpretation of the measurements of the Lunar Prospector (NASA) spaceprobe, there is some water ice in the polar regions of the Moon (see [23]). But most probably these water reserves are located on the permanently shadowed slopes and bottoms of some polar craters, under a rather thick layer of regolith, i.e. not easily accessible and probably exhausted relatively quickly if used for propellant production. Even the movement of "terrestrial" vehicles is much more energy consuming there than on an asteroid. The two week long nights also pose some problems. The utilisation of the Moon (especially the water reserves) might be objected by some great powers and such objections might become disastrous (a great power may destroy the organisation supporting the colony on the Earth or even attack the colony directly—the Moon is quite near, such an action would not require great preparations).

A possible analogy to this scenario is the persecution of the Jews during World War II and the foundation of the state of Israel after the war (this analogy is a limited one, too: creating a state on a fertile land is far more easier than on an airless celestial body, but if one takes into consideration the enormous defence costs caused by the enemy neighbours, then the "emigration to space" might look like a viable option). There were other persecuted minorities in earlier times, too, who decided to move to a new homeland. E.g. there were some Protestant groups (Puritans, Congregationalists, Baptists, Quakers etc.) in Europe who emigrated to North America in the 17th–18th centuries and played an important role there (some of those groups are quite prosperous even today). In the popular book of O'Neill ([24], Chap. 11) a "homesteading" scenario is described in which a small private group is moving to an asteroid. As the background of this scenario, it is assumed that large space colonies exist already and the key technologies listed in Section 2 are not just developed but so widely used that their price is not prohibitive even for private persons (it seems to be a rather improbable assumption, even in the far future).

4. THE "POWER SHOW" SCENARIO

The greatest venture of astronautics to date (the Apollo project) was initiated in order to win the "space race". Such races are not uncommon among rival great powers, although typically these appear as "armament races" (see e.g. the British–German "fleet race" at the beginning of the 20th century). But in case of an intensive "cold war" any "impressive thing" may be used to show off the mightiness of a country (or an alliance), and a permanent colony on an asteroid certainly can prove the high-tech skills of its creators. A simple "plant the flag and leave" mission could cause more disillusionment than pride in the long run ("we have spent so much money and we just got some stones") therefore, it is quite probable that such missions will not be considered as proper means of a "technology show". What is even more important, asteroid colonies may have very serious military implications prospectively (see the next scenario) i.e. just from a purely defensive viewpoint, one may consider the foundation of asteroid colonies as a necessity. This consideration in itself justifies the foundation of the colony on an asteroid and not on the Moon, but the same objections which were raised against a Moon colony in the previous section are applicable here, too. The present situation of the world politics with only one superpower seems to be rather exceptional, it is much more common when there are several great powers with more or less equal (although sometimes rather incomparable) forces. It is quite probable that world politics will revert to this "normal situation" within a historically short time, and when the resulting great powers will have enough free resources they may start some "races".

From a scientific viewpoint an asteroid colony also would be more useful than a Moon colony: there would be better possibilities of radio astronomy (very long baselines, receivers very far from

the terrestrial noises), normal and infrared astronomy (sensors far from strong lights and infrared sources), microgravity experiments (these are not possible on the Moon). The asteroids are rather diverse objects and our knowledge of them is rather limited, this would be true even after several successful "asteroid orbiter" missions (like NASA's NEAR). This lack of knowledge also justifies the foundation of an asteroid colony.

5. THE "MILITARY" SCENARIO

Recent studies have shown that asteroid and comet impacts have played an important role in the evolution of the Earth's biosphere by triggering mass extinctions (see [25]). In connection with this theory the effects of asteroid impacts were analysed in detail (see [26]). It was shown that even medium size near-Earth asteroids (with diameters between 0.2 and 2 km) may cause quite big explosions (with energies between 1000 and 100,000 Mt TNT equivalents) on the surface of the Earth. These energies are much bigger than the possible energy releases of the largest nuclear weapons ever built, such an explosion might destroy a big country or a small continent. If a great power manages to create several "military asteroids" (which may be put into action in a "not too long time" after the outbreak of a war) then it will get a great military advantage, comparable with the present advantage of the nuclear powers over the other countries. Military power is one of the most important founding elements of a great power's status, therefore, it is very probable that the leaders of some great powers will spare no efforts in order to create such "military asteroids" if the technological possibility appears.

There are approximately 35,000 medium size near-Earth asteroids which might be turned (theoretically) into "military asteroids" (see [27]). The orbit of a "military asteroid" must satisfy the following criteria:

- its orbital period must be an exact multiple of the Earth's orbital period (0.5, 1, 2 yr etc.);
- the asteroid's orbit must pass quite closely to the Earth's orbit (e.g. the minimum distance should be less than 0.01 AU);
- the asteroid must cross a nodal point of its orbit when the Earth is near this nodal point.

In order to modify the orbit of an asteroid one must build a very big electrical propulsion engine on it (e.g. an engine with 100 km/s ejection speed and with 100 kg/s reaction mass consumption). The thrust of such an engine would be comparable with the thrust of the biggest (now existing) chemical rockets. If this engine operates continuously, then it can modify the orbit of a medium size asteroid with a delta $V = 0.05$–1 km/s yearly. Within 10–30 years the required orbit might be reached. The propulsion engine must be operated regularly even after reaching this orbit, because the "close encounters" with the Earth will perturb the asteroid's orbit significantly. After placing the asteroid to the proper orbit, it can be positioned to hit the Earth in a short time if it is only several months away from its "near Earth" nodal point. In order to have an asteroid in "firing position" rather frequently (i.e. once in every 3–4 months) one must create 5–15 such "military asteroids" with properly arranged "near-Earth" nodal points around the Earth's orbit.

The building of such a big electrical propulsion engine on an asteroid is a very difficult task, it's total mass will be probably several million tons (most of this mass is not necessary for the rocket engine itself, but for the power supply system which must have a solar collector surface of a thousand square kilometres at least). This mass is comparable with the mass of a large "space colony" suggested by O'Neill. The building of such a "space colony" seems to be quite improbable even in the far future but a "military asteroid" may provide such a military advantage that in the future some great powers (or military alliances like the NATO) may make the necessary efforts. The building of the propulsion system probably requires a large asteroid colony (100–200 persons at least) but operating the engine is a much less demanding task (i.e. the "builder group" can be moved to the next selected asteroid).

The discussion of such military developments might seem to be condemnable and dangerous, but one must take into consideration the following too:

- The majority of the new technologies create new military opportunities and sooner or later these opportunities are leading to the development of new weapons. This process is inevitable as history has shown many times, therefore, it would be unwise if the democratic powers would refrain from such developments because of moral, financial reasons, etc. In this case dictatorial regimes would take the lead in this field (a dictatorship usually rests on military power—it is a matter of life and death to increase their military capabilities). Countries with dictatorial regimes tend to be poorer than countries with democratic governments, but in a large country the nec-

essary funds could be raised even if the per capita GDP is low (see the recent appearance of rockets with nuclear warheads in some developing countries).

- Excluding the military possibilities from a field of research inevitably leads to the very serious decrease in the funding of that field (every major power spends a very significant part of its R&D funds on military research). This leads to diminishing capabilities in that field of research (and technology) and if in future, that field becomes important economically, militarily or in any other way then the whole country will suffer the consequences of backwardness. In space research it would be very important to co-ordinate the civilian and military efforts (see [28] and [29]).
- International politics and its subcomponents (e.g. the countries possessing highly destructive weapons) are very complex systems and their behaviour can be quite counter-intuitive. One might think that the appearance of the nuclear bombs in the arsenals of the great powers (and especially their combination with intercontinental missiles which provides a very advantageous "first strike" capability) leads to serious instabilities and quite soon to nuclear war. But in retrospect, it is obvious that the "cold war" era was a remarkably peaceful period of history. There are probably many causes behind this phenomenon but almost certainly the most important cause was the following: the most powerful (and technologically best) nuclear arsenal was controlled by a responsible, democratically elected government. It guaranteed that this nuclear arsenal will not be used for aggressive purposes but also guaranteed that any aggressive use of nuclear weapons will be retaliated. Therefore, if there will be a technological opportunity for another major leap in weapons development, then it is in our best interest that a democratic great power takes the lead in this field.
- The effects of a major nuclear war are not known from experience (luckily for us!), only from computer simulations. The results (seriousness of global effects) are debatable ("nuclear winter" vs. "nuclear autumn" scenarios, see [30]). The same uncertainty exists in the simulation of the impacts of smaller asteroids (200–500 m diameter, with impact energy roughly equivalent to the total power of the present nuclear arsenals, see [31]). A dictator in a "tight situation" might be tempted to believe that the global effects will not be serious (and he might be even right, especially if there is no counterforce which could retaliate) but a democratic government, bound by moral considerations, certainly will not act in this way.

It must be noted here that in recent studies, not only the asteroid impact hazard was examined but suggestions were made to mitigate this hazard. It was shown that on the present level of technology the most reasonable asteroid deflection system (from the viewpoint of response time and development cost) is an interplanetary rocket with a large nuclear warhead (see [32]). Such a system can be used not only for its intended purpose but for deflecting an asteroid to impact the Earth, too. The opportunity of such a misuse of a deflecting system with a 100 Mt warhead (this can be considered as the present technological limit) appears in every few years (see [33]) if one already knows the orbits of all the near-Earth asteroids with diameters 1 km or more. Detecting all such asteroids is a rather nontrivial task (see [34]) and even having the complete catalogue the "few years" intervals between the possible applications is too long for an active strategic weapon. Another problem is the aiming accuracy, the effect of the nuclear blast on the asteroid cannot be regulated very precisely i.e. the point of the impact will be rather unsure. Therefore, it is highly improbable that a regular army would ever consider the utilisation of such an asteroid deflection system as a weapon, but the danger of "terrorist use" is real, this threat must be taken seriously.

6. THE "INDUSTRIAL" SCENARIO

The potential value of asteroids as material resources have been investigated by many researchers. The estimated market value of a 100 m diameter iron asteroid is 5 billion USD (see [35]). Another estimate for the value of a 1 km diameter iron asteroid is 1 trillion USD (see [36]). From these huge sums one may infer that "asteroid mining" must be a very profitable venture. But the mentioned prices are valid on the surface of the Earth only, and there isn't any cheap method to land an asteroid softly. Even if we assume that the orbit of an asteroid can be modified using the technology described in the previous section, the following two problems remain:

- moving the asteroid to an Earth-centred orbit,
- moving the pieces of the asteroid to the surface of the Earth.

The first problem can be solved by the modification of the asteroid's orbit, but if one uses only the propulsion system built on the asteroid then it will take too much time (except if the original orbit was very close to the Earth's orbit, but this is rather improbable). But if one uses some gravity-assist manoeuvres, too (in the Earth–Moon system one may invent quite tricky trajectories) then the transfer to an Earth-centred orbit might be solved in a reasonable time. The second problem is even more difficult. Since the beginning of the "space age" a very important goal was the development of a cheap Earth-to-orbit (and back) transfer system, and even after many ingenious projects (like the Space Shuttle of NASA) the Earth-to-orbit transfer prices are not much lower than in the 1960s. It is quite possible that nobody will be able to solve to this problem in a "historically short" time. Therefore, the "asteroid mining" might remain unremunerative for a very long time.

But if we assume that a "military asteroid" can be manoeuvred to an Earth-centred orbit, another possibility emerges. An early (and much investigated, see [28] and [37]) suggestion for the practical utilisation of space technologies is the creation of "solar power satellites" (SPS). An SPS is essentially a large solar power converter and some power distribution devices and a large microwave transmitter. A "military asteroid" described in the previous section already contains the first two major components and it contains a space manufacturing system, too, therefore, it is possible to create the third major component (the microwave transmitter) mostly from asteroidal materials. If we assume that the technology developed according to the "military" scenario will be sold at reasonable prices to private companies, then the conversion of asteroids into solar power satellites might be a profitable business. This scenario fits well into the general scheme of some other major high-tech development scenarios of the 20th century:

- nuclear reactors were firstly used (and developed) for plutonium production (in order to make nuclear bombs) and only later were utilised in electric power plants,
- large liquid-propellant rockets were developed (and, unfortunately, even used during the World War II) to deliver heavy warheads to faraway targets quickly and only later were modified and improved (by the same development teams!) to carry satellites and spaceships.

Therefore the combination of the "military" and the "industrial" scenarios seems to be quite probable.

7. CONCLUSION

All the scenarios described above might become ponderable possibilities in the future if one assumes that the necessary technologies will be developed. But considering the very high development costs, the first asteroid-based colonies probably will be created according to the "power show" scenario, with massive governmental support. The most important activity of these colonies (in addition to scientific research) will be the development and testing of space manufacturing technologies. After reaching a high level in these technologies, it will be possible to create some "military asteroids". But the creation of such a weapon system will be very expensive, there will be an obvious need to make some profit from such a big investment. Therefore, it is probable that the governments will licence the use of space manufacturing technologies (or even sell some outdated "military asteroids") to private groups (with strict regulations, of course). These private groups will utilise the asteroids according to the "escapist" or "industrial" scenarios. In a later time when there will be many asteroidal colonies with many inhabitants, the formation of an "asteroidal society" may start.

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